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(54) Title: METHOD FOR COATING A CALCIUM PHOSPHATE COMPOUND ONTO A METALLIC MATERIAL

(57) Abstract

A method for coating a calcium phosphate compound onto a metallic material, which method comprises electrodepositing the calcium phosphate compound from an aqueous solution containing calcium ions, phosphate ions and a complex forming agent onto an electrode comprising the metallic material. The coating layer obtained by this process comprises fine and uniform particles of a calcium phosphate compound and has a high bond strength.

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METHOD FOR COATING A CALCIUM PHOSPHATE COMPOUND ONTO A METALLIC MATERIAL

The present invention relates to a method for coating a calcium phosphate compound onto a medical implant metallic material such as an artificial articulation, an artificial bone, or an artificial root of a tooth.

As an implant material used as a substitute for a hard tissue of an organism lost by disease or by accident, titanium, titanium alloys, cobalt-chromium alloys, stainless steel and the like have hitherto been employed. However, these metallic materials do not bind directly to the tissue of the organism, thus raising problems of low initial bonding strength, and loosening over longer periods of time.

As a method for improving the initial bonding strength of the implant material, a method has been developed in which a bone cement including poly methyl methacrylate (PMMA) is injected into a site to be treated and solidified. However, in this method, there is a problem that the heat generated by the solidifying reaction affects the surrounding tissue.

In order to solve these problems, a method has been proposed utilizing a metal implant material on which a calcium phosphate compound such as hydroxyapatite is coated on its surface. In this method, by connecting the implant material directly with hard tissue such as bone via a bioactive coating layer, the initial bond strength and stability for a prolonged time may be improved.

As methods for forming such a coating layer, plasma spraying, sputtering, dip coating and sol-gel coating methods have hitherto been employed. Of these, the plasma spraying method is a relatively practical method, but has problems such as the formation of

soluble by-products or amorphous components, which results in the dissolution of the coating layer after implantation, and ablation at a gap between a substrate and the coating layer. The methods for forming the coating layer other than the plasma spraying method also encounter problems such as an insufficient bonding strength and nonuniformity of the coating layer, and therefore are not sufficiently practical.

We have now developed a method for coating a calcium phosphate compound by which a coating layer composed of fine and uniform particles of a calcium phosphate compound and having a high bond strength is readily formed.

According to the present invention, there is provided a method for coating a calcium phosphate compound onto a metallic material, which method comprises electrodepositing the calcium phosphate compound from an aqueous solution containing calcium ions, phosphate ions and a complex forming agent onto an electrode comprising the metallic material.

In a particular aspect the present invention provides a method as described above wherein the calcium phosphate compound is hydroxyapatite, and the pH of the aqueous solution is controlled to be not less than 4.0 for the electrodepositing.

In a further aspect the present invention provides a method wherein the calcium phosphate compound salt is other than hydroxyapatite, and the method further comprises the step of immersing the material having the calcium phosphate compound electrodeposited thereon in an aqueous solution having pH of not less than 4.0, whereby the calcium phosphate compound salt is converted to hydroxyapatite.

In the coating method of the present invention, a calcium phosphate compound salt is electrodeposited

onto a metallic material from an aqueous solution containing calcium ions, phosphate ions and a complex forming agent.

The material to be coated is not limited as long as it is made of metal and does not spoil the effect of the present invention. Metals which are superior in anti-corrosive properties and do not exhibit toxicity in having organisms, such as titanium, a titanium alloy, stainless steel or a cobalt-chromium alloy may be employed.

As the configuration of the material to be coated, any configurations may be employed including a plate, a sphere, a cylinder, a prism, a circular cone, a pyramid, and a variety of other forms imitating a tooth or a bone.

The aqueous solution containing calcium ions, phosphate ions and a complex forming agent may be prepared by dissolving in water a compound containing calcium ions, a compound containing phosphate ions, and a complex forming agent.

The compound containing calcium ions may include, e.g. $Ca(OH)_2$, $Ca(NO_3)_2$, CaC_{12}, $Ca(CH_3COO)_2$, calcium citrate or calcium lactate. The compound containing phosphate ions may include, e.g. H_3PO_4, Na_3PO_4, $(NH_4)_3PO_4$, K_3PO_4, or a salt in which a part of the cation in these salts is substituted by hydrogen (e.g. $(NH_4)_2HPO_4$). Instead of employing both a compound containing calcium ions and a compound containing phosphate ions, a compound containing both phosphate ions and calcium ions, such as hydroxyapatite, calcium tertiary phosphate, calcium quaternary phosphate or calcium hydrogen phosphate, may be employed.

As to the concentration of the calcium ions and the phosphate ions in the above aqueous solution, the concentration of $[Ca^{2+}]$ is preferably 0.01 to 2.0 mol/l,

and the concentration of $[PO_4^{3-}]$ is preferably 0.005 to 2.0 mol/l. As to the ratio of calcium ions and phosphate ions in the aqueous solution, the Ca/P molar ratio is preferably 1.0 to 3.0. By suitably regulating these ion concentrations, the thickness of the coating layer may be controlled.

The complex forming agent may include citric acid, ethylenediaminetetraacetic acid (EDTA), lactic acid or nitrilotriacetic acid (NTA). The preferable concentration of the complex forming agent in the aqueous solution is 0.01 to 1.0 mol/l.

In the method of the present invention, a calcium phosphate compound salt is electrodeposited on the metallic material to be coated as an electrode. For the electrodeposition, the counter electrode is not limited as long as it does not reduce the effect of the present invention, and may include the same metals as the material to be coated, and electrically conductive plastic materials. The distance between the electrodes in the aqueous solution is preferably 1 to 50mm.

The voltage for the electrodeposition is preferably 1 to 100V/cm^2. By suitably regulating the voltage, the film forming rate and construction of the coating layer may be controlled.

The duration of the electrodeposition is preferably from 3 to 120 minutes. By suitably adjusting the duration of the electrodeposition, the thickness of the coating layer may be controlled.

Upon the electrodeposition, the temperature of the aqueous solution is preferably maintained at a constant temperature within a range of from 15° to 100°C. By maintaining the aqueous solution at a higher temperature, the time for the electrodeposition may be shortened. Also, if the aqueous solution is maintained at a higher temperature, a coating layer having a

larger particle size may be obtained, while if it is maintained at a lower temperature, a coating layer having a smaller particle size may be obtained.

Upon the electrodeposition, by regulating the aqueous solution at a pH of not less than 4.0, preferably 4.0 to 12.0, hydroxyapatite may be electrodeposited as the coating layer.

The aqueous solution may be regulated at a pH of not less than 4.0 by adding a pH regulating agent to the aqueous solution. It is not required to dissolve all of the pH regulating agent before beginning the electrodeposition. The agent may be added little by little after beginning the electrodeposition. That is, if the pH of the aqueous solution is not less than 4.0 when the calcium ions, phosphate ions and the complex forming agent are dissolved therein, the pH regulating agent is not required to be added before beginning the electro-deposition, and may be added little by little after beginning the electrodeposition in order to prevent the pH value dropping below 4.0 during the electrodeposition, so that hydroxyapatite may be electrodeposited.

As the pH regulating agent, ammonia, sodium hydroxide or potassium hydroxide may be employed. In terms of preventing contamination by undesired metal ions, ammonia is particularly preferred. In the case of adding the pH regulating agent little by little during the electrodeposition, the pH regulating agent is preferably prepared as an alkaline solution by dissolving the agent in water. The preferred concentration of the alkaline solution is, for example, in the case of employing ammonia, 0.03 to 0.5 mol/l, and in the case of employing sodium hydroxide, 0.01 to 0.1 mol/l.

The calcium phosphate compound in the coating layer obtained by the coating method of the present invention may include calcium hydrogen phosphate dihydrate ($CaHPO_4.2H2O$), monetite ($CaHPO_4$), calcium tertiary phosphate ($Ca_3(PO_4)_2$), or the aforementioned hydroxyapatite.

If a layer of a calcium phosphate compound salt other than hydroxyapatite is obtained by the electrodeposition, the layer of the calcium phosphate compound other than hydroxyapatite obtained by the electrodeposition may be converted into the more stable hydroxyapatite by immersing the coated material having the calcium phosphate compound salt electrodeposited thereon in an aqueous solution having pH of not less than 4.0, preferably 4.0 to 12.0. The step may be performed by, but is not limited to, adjusting the pH of the aforementioned aqueous solution employed upon the electrodeposition to the desired pH value by, e.g. adding alkali while the coated material is kept immersed in the aqueous solution, or by transferring and immersing the coated material into another aqueous solution, the pH of which has been adjusted to the desired pH value by, e.g. adding alkali after the electrodeposition. The preferred duration of the immersion is from 10 to 50 hours. As the alkali, ammonia, sodium hydroxide or potassium hydroxide may be employed. In terms of preventing contamination by undesirable metal ions, ammonia is particularly preferred.

The coating layer of the calcium phosphate compound obtained by the method of the present invention may further be subjected to a heat treatment for improving bonding strength. Even the heat treatment at relatively low temperature at which the coated material is not damaged, e.g. about 750^{0}C in the case of

titan, can improve the bonding strength of the coating layer. It is believed that the bonding strength of the coating layer can be improved at such a relatively low temperature since the aqueous solution as a coating bath has an electrophoresis effect so that the coating layer is formed of finer particles on the material to be coated as the electrode, than that of a conventional layer.

With the method for coating of the present invention, a coating layer of a calcium phosphate compound is formed by electrodeposition, and thus a calcium phosphate compound composed of fine and uniform particles may be coated even on the surface of a metal material having a complicated configuration. Therefore, the present invention is useful as a method for improving the biological compatibility of implant materials.

The present invention is described in more in detail with reference to Examples herein below, but the present invention is not limited thereto. In the following Examples, all of the reagents used are manufactured by BDH.

EXAMPLE 1

0.1 mol of calcium hydroxide, 0.06 mol of orthophosphoric acid and 0.2 mol of citric acid were dissolved in 1 litre of distilled water. This aqueous solution was poured into three vessels in water baths, and controlled at temperatures of 20^{0}C, 60^{0}C and 90^{0}C, respectively. In each of the vessels, two pure titanium plates (50 x 20 x 1 mm) were inserted at an electrode separation of 10 mm, and electrodeposition was performed at DC 20V for 30 minutes. As a result, porous coating layers of calcium hydrogenphosphate

dihydrate ($CaHPO_4.2H_2O$) having thicknesses of 5μm, 10μm and 20μm, respectively, were obtained on the surface of each cathode.

EXAMPLE 2

0.1 mol of calcium nitrate, 0.06 mol of ammonium phosphate and 0.1 mol of EDTA were dissolved in 1 litre of distilled water. This aqueous solution was poured into a vessel in a water bath, and controlled at a temperature of 95^{0}C. In the vessel, a pure platinum plate (anode, 50 x 20 x 0.1 mm) and a stainless-steel SUS316L plate (cathode, 50 x 20 x 1 mm) were inserted at an electrode separation of 10 mm, and electrodeposition was performed at DC 10V for 30 minutes. As a result, a coating layer of monetite ($CaHPO_4$) having a thickness of 10μm was obtained on the surface of the cathode.

EXAMPLE 3

0.2 mol of calcium hydroxide, 0.12 mol of orthophosphoric acid and 0.5 mol of lactic acid were dissolved in 1 litre of distilled water. This aqueous solution was poured into three vessels in water baths, and controlled at temperatures of 20^{0}C, 60^{0}C and 90^{0}C, respectively. In each of the vessels, two plates (50 x 20 x 1 mm) of a titanium alloy containing 6wt% of aluminum and 4wt% of vanadium (referred to hereinafter as Ti-6Al-4V alloy) were inserted at an electrode separation of 10 mm, and electrodeposition was performed at DC 10V for 20 minutes. As a result, a dense coating layer of monetite having thicknesses of 10μm, 15μm and 30μm, respectively, were obtained on the surface of each cathode.

EXAMPLE 4

0.1 mol of calcium hydroxide, 0.06 mol of orthophosphoric acid and 0.3 mol of lactic acid were dissolved in 1 litre of distilled water. This aqueous solution was poured into a vessel in a water bath, and controlled at a temperature of 20°C. In the vessel, two pure titanium plates (50 x 20 x 1 mm) were then inserted at an electrode separation of 10 mm, and electrodeposition was performed at DC 5V for 10 minutes. As a result, a dense coating layer of calcium hydrogenphosphate dihydrate having a thickness of 30μm was obtained on the surface of the cathode.

After finishing the electrodeposition, ammonia was further added to the aqueous solution to adjust the pH to 5.0, and the cathode was immersed therein for 24 hours. As a result, the coating layer of calcium hydrogenphosphate dihydrate was converted into a uniform hydroxyapatite coating layer.

EXAMPLE 5

The coated alloy plate obtained in Example 3 with a 30μm thick coating layer was subjected to a heat treatment at 750°C for 60 minutes. Bonding strengths before and after the heat treatment were measured according to JIS H8666 "ceramic spraying test method" for comparison. As a result, the bonding strength was improved from 13MPa to 22MPa while the alloy plate, i.e. the coated material, was not damaged.

COMPARATIVE EXAMPLE 1

On a Ti-6Al-4V alloy plate which is the same as that of Example 3, monetite was sprayed by a plasma

spray gun manufactured by METCO Co. under the trade name of METCO 9MB to give a film thickness of 30μm. The spraying was carried out under the conditions of 500A, 40V, at a spraying distance of 50mm, using a mixed gas of Ar:H_2 of 100:3.

The bonding strength of the layer measured by the same method as Example 5 was 5MPa.

EXAMPLE 6

0.1 mol of calcium hydroxide, 0.06 mol of orthophosphoric acid and 0.2 mol of lactic acid were dissolved in 1 litre of distilled water. This aqueous solution was poured into three vessels in water baths, and controlled at the temperatures of 20^{0}C, 60^{0}C and 90^{0}C, respectively. In each of the vessels, two pure titanium plates (50 x 20 x 1 mm) were inserted with the distance of 10 mm. An aqueous solution containing 0.1mol/l of ammonia was added dropwise into the vessels until the pH of the solution reached 4.5. Electrodeposition was then performed at DC 5V for 10 minutes while the aqueous ammonia solution was added dropwise using a low-speed motor with monitoring of the pH to be maintained at 4.5. As a result, dense coating layers of hydroxyapatite having thicknesses of 5μm, 20μm and 30μm, respectively, were obtained on the surface of each cathode. During the whole reaction, the pH was maintained at 4.5±0.2.

EXAMPLE 7

0.1 mol of calcium nitrate, 0.06 mol of ammonium phosphate and 0.2 mol of citric acid were dissolved in 1 litre of distilled water. This aqueous solution was poured into two vessels in water baths, and controlled

at temperatures of 60^0C and 90^0C, respectively. In each of the vessels, two Ti-6Al-4V alloy plates (50 x 20 x 1 mm) were inserted at an electrode separation of 10 mm. 0.05mol/l of sodium hydroxide was added dropwise into the vessels until the pH of the solution reached 5.0. Electrodeposition was then performed at DC 10V for 20 minutes while sodium hydroxide was added dropwise using a low-speed motor with monitoring of the pH to be maintained at 5.0. As a result, coating layers of hydroxyapatite having thicknesses of 10μm and 25μm, respectively, were obtained on the surface of each cathode. During the whole reaction, pH was maintained at 5.0±0.2.

EXAMPLE 8

The coated alloy plate obtained in Example 7 with a 25μm coating layer was subjected to a heat treatment at 750^0C for 60 minutes. Bonding strengths before and after the heat treatment were measured by the same method as in Example 5 and compared. As a result, the bonding strength was improved from 15MPa to 25MPa while the alloy plate, i.e. the coated material, was not damaged.

COMPARATIVE EXAMPLE 2

On the Ti-6Al-4V alloy plate which is the same as that of Example 7, hydroxyapatite was sprayed by a plasma spray gun manufactured by METCO Co. under the trade name of METCO 9MB to give a film thickness of 25μm. The spraying was carried out under the conditions of 500A, 40V, spraying distance of 50mm, using a mixed gas of $Ar:H_2$ of 100:3.

The bonding strength of the layer measured by the same method as in Example 5 was 6MPa.

CLAIMS:

1. A method for coating a calcium phosphate compound onto a metallic material, which method comprises electrodepositing the calcium phosphate compound from an aqueous solution containing calcium ions, phosphate ions and a complex forming agent onto an electrode comprising the metallic material.

2. A method as claimed in claim 1, wherein the calcium phosphate compound is hydroxyapatite and the pH of the aqueous solution is maintained at a pH of at least 4.0 during the electrodeposition step.

3. A method as claimed in claim 1 wherein the calcium phosphate compound salt is other than hydroxyapatite and the method further comprises immersing the material having the calcium phosphate compound electrodeposited thereon in an aqueous solution having a pH of not less than 4.0, whereby said the calcium phosphate compound is converted to hydroxyapatite.

4. A method as claimed in any one of the preceding claims wherein the metallic material is titanium, a titanium alloy, stainless steel or a cobalt-chromium alloy.

5. A method as claimed in any one of the preceding claims wherein the compound containing calcium ions is $Ca(OH)_2$, $Ca(NO_3)_2$, CaC_{12}, $Ca(CH_3COO)_2$, calcium citrate or calcium lactate.

6. A method as claimed in any one of the preceding claims the compound containing phosphate ions is H_3PO_4, Na_3PO_4, $(NH_4)_3PO_4$, K_3PO_4 or $(NH_4)_2HPO_4$.

7. A method as claimed in any one of claims 1 to 4 wherein a compound is employed containing both calcium ions and phosphate ions which is hydroxyapatite, calcium tertiary phosphate, calcium quarternary phosphate or calcium hydrogen phosphate.

8. A method as claimed in any one of the preceding claims wherein the complex forming agent is citric acid, ethylenediaminetetraacetic acid (EDTA), lactic acid, or nitrilotriacetic acid (NTA).

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 97/02527

A. CLASSIFICATION OF SUBJECT MATTER
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According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C25D A61L A61K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CHEMICAL ABSTRACTS, vol. 120, no. 10, 7 March 1994 Columbus, Ohio, US; abstract no. 116877, INOE, KYOSHI ET AL: "Surface treatment of prosthetic implants" XP002049280 see abstract & JP 05 285 212 A (ISHIFUKU METAL IND, JAPAN) ---	1,4-8

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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1

Date of the actual completion of the international search	Date of mailing of the international search report
5 December 1997	19/12/1997

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INTERNATIONAL SEARCH REPORT

Inter nal Application No
PCT/GB 97/02527

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	DATABASE WPI Section Ch, Week 9348 Derwent Publications Ltd., London, GB; Class D22, AN 93-382264 XP002049281 & JP 05 285 212 A (ISHIFUKU METAL IND CO LTD) see abstract ---	1,5-8
A	US 5 413 693 A (REDEPENNING JODY G) 9 May 1995 see the whole document ---	2,3
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